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Distributed Generation in Power Systems: An Overview and Key Issues

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Abstract

The necessity for smart electrical systems having minimum technical loss and environmental impact is providing impetus to go for Distributed Generations (DGs) which may offer several other advantages such as reduced transmission and distribution system resources, increased reliability, better power quality, etc. However, depending on the system configuration and management, these advantages may not be true. Moreover, due to structural and managerial changes in the electricity supply industry motivated with introduction of completion, the role of small generations distributed in the low/medium voltage network has gained importance. This paper adopts a systematic approach by focusing on the most important research areas related to the distributed generations. Various DG technologies are described and penetration of DGs in the Indian system has been discussed. This paper also highlights the key issues in the DG integration in power systems.

Introduction

With current initiatives on smart grid and sustainable energy, distributed generations (DGs) are going to play vital role in the emerging electric power systems [1]. To fully exploit the potential advantages of DGs, it is necessary to re-think the basic philosophy governing the electricity distribution system. The future active network will effectively and efficiently link small and medium scale electric power sources with costumer demands. DG is often used as back-up power to enhance reliability or as a means of deferring investment in transmission and distribution networks, avoiding network charges, reducing line losses, deferring construction of large generation facilities, displacing expensive grid-supplied power, providing alternative sources of supply in markets and providing environmental benefits. However, depending on the system configuration and management, these advantages may not be true. In recent years, DG has become an efficient and clean alternative to the traditional electric energy sources, and recent technologies are making DGs economically feasible.

Now-a-days, DGs are the part of distributed energy resources (DERs) which also include energy storage and responsive loads. The major driving forces behind the increased penetration of DGs can be categorized into environmental, commercial and regulatory factors. There are several small generators which produce very small or no greenhouse gas emissions. Another environmental driver is to reduce the transmission and distribution expansion along with the avoidance of large power plants. In the commercial driver, the uncertainty in electricity markets favors small generation schemes and DGs are now cost effective to improve the power quality and reliability. Diversification of energy sources to enhance the energy security and support for competition policy are the major regulatory drivers. The attractive proposition of DG is that it is distributed round the network close to customers and DGs represent diverse technologies and primary energy sources.

There has been tremendous research work in the areas of DG technologies, sitting and sizing of DG, impact studies of the increased penetration of DG, economic and financial analysis coupled with DG integration, etc. Owing to the vast scopes, it is difficult for researchers, policy makers, and academicians to read all the related materials. Various resources related to the DGs technology and integration are presented. It is important for the researcher to understand the key issue of the large penetration of distributed generation in the power system. This paper addresses these key concerns as well.

1. Distributed Generation Technologies

Due to maturing technologies and increasing size of DGs, which play a significant and topical phenomenon in power system, there is as yet no universal agreement on the definition of DGs. These are also known as embedded generations or dispersed generations [1]. Current definition of DG is very diverse and range from 1kW PV installation, 1 MW engine generators to 1000 MW offshore wind farms or more [2, 16].

The some of the popular DG technologies are listed below:

- Reciprocating Diesel or Natural Gas Engines [3-5]
- Micro-Turbines [6]
- Combustion Gas Turbines [7-8]
- Fuel Cells [9-12]
- Photovoltaic (PV) system [13-18]
- Wind Turbines [19-24]

The detailed discussion of application, recent trends, benefits and challenges of DG is given in ref. [16,25-26]. **Table 1** provides a brief overview of the most commonly used DG technologies and their typical module size.

Table 1: Distributed generators with available size

No.	Technology	Typical available size power module
1	Combined Cycle Gas Turbine	35-400 *MW*
2	Internal Combustion Engines	5 *kW* -10 *MW*
3	Combustion Turbine	1-250 *MW*
4	Micro-Turbines	35 *kW*-1 *MW*
5	Fuel Cells, Phos.Acid	200 *kW* -2 *MW*
6	Fuel Cells, Molten Carbonate	250 *kW* -2 *MW*
7	Fuel Cells, Proton Exchange	1-250 *kW*
8	Fuel Cells, Solid Oxide	250 *kW*-5 *MW*
9	Battery Storage	0.5-5 *MW*
10	Small Hydro	1-100 *MW*
11	Micro Hydro	25 *kW* -1 *MW*
12	Wind Turbine	200 *W* -3 *MW*
13	Photovoltaic Arrays(PV Arrays)	20 *W*-100 *kW*
14	Solar Thermal, Central Receiver	1-10 *MW*
15	Solar Thermal, Lutz System	10-80 *MW*
16	Biomass Gasification	100 *kW*-20 *MW*
17	Geothermal	5-100 *MW*
18	Ocean Energy	0.1-1 *MW*

The technologies 10-18 can be considered as renewable DGs. The other technologies could also be called renewable DG if they are operated with bio-fuels. Similarly, to the centralized generation, the following three generation technologies are normally used for distributed generation: synchronous generator, asynchronous generator, and power electronic converter interface [28-30]. An Electric Power Research Institute's (EPRI) study forecasted that by the year 2010, 25% of the newly installed generation will be DGs, and a similar study by Natural Gas Foundation believes that the share of DG in new generation will be 30% [31-32].

2. Role and Integration of DGs in the Power Systems

Different types of Distributed Generations (DG) are available and it is expected to grow in the future years. DG includes the application of small generators, scattered throughout a power system, to provide the electric power needed by electrical customers. Such locally distributed generation integrated to power system has several merits from the view point of environmental restriction and location limitations, as well as transient and voltage stability in the power system [2, 33].

A lot of work has been reported in literature for optimal location of DGs integrated in the distribution network [34-36]. The suitable size of DGs for efficient and reliable supply is also a concern. However, the size of the DGs depends on the several factors such as availability of input energy, space, economic and environmental concerns [37]. IEEE has set up interconnecting standards for distributed resources [38]. An overview of control and grid synchronization for distributed power generation systems is presented in [39]. A robust stability analysis of voltage and current control for distributed generation systems [40] and, value-based methods try to find the best tradeoff between the costs and benefits of DG placement and then find the optimal types of DG and their corresponding locations and sizes in distribution feeders [41].

In characterization of the loss allocation technique, derivative based methods, circuit based methods and tracing method are discussed in [42]. In [43], a methodology for planning of DG in DS using safety index (ratio of reserve power to its standard deviation) has been proposed. Multi objective performance index-based size and location determination of distributed generation in distribution systems with different load models has been proposed in [44] and found that load models can significantly affect the optimal location and sizing of distributed generation (DG) resources in distribution systems. **Table 2** shows the various methods used for DGs location and integration in the power systems.

Table 2: Methods used in DG location and integration

Methods used in DG location and integration	References
Genetic Algorithm	[35-36, 41]
Ant Colony Optimization	[45]
Tabu search	[34-35, 46]
Analytical expression	[47-48]
Particle swarm	[49]

In the present day, power system is becoming more and more complex in structure, operation, control, management and ownership. These DGs are required to solve various existing problems of power systems and can be useful in future for providing the ancillary services, aggregation technology etc.

3. Distributed Generations in India

The Government of India has taken several measures including fiscal and financial incentives, preferential tariff for the promotion and proper use of renewable energy systems/devices in the country. Significant achievements have been made, with the establishment of over 13700 MW grid-interactive renewable power generation capacity, which is about 9% of the total installed capacity in the country. Of this, about 6795 MW capacity has been added during the 10th Plan, i.e., 2002-07 against the plan target of 3075 MW. In addition, over 5.5×10^6 off-grid/ decentralized renewable energy systems/devices, mainly biogas plants and solar photovoltaic lighting systems, have been deployed for provision of basic energy needs of cooking and lighting in rural households.

There are difficulties in the exploration of renewable energy sources in the country. The major constraints faced in this field are inherent intermittent nature of renewable energy sources leading to low capacity utilization factors ranging from about 17% to 70%, depending on resource and location, grid synchronization limitations on account of intermittent nature of supply, relatively higher capital investment compared to conventional power projects; and requirement of preferential tariffs apart from other fiscal and/or financial concessions to make investment in renewable power a commercially attractive proposition [50-51]. **Table 3** represents the various DGs options in India.

Table 3: Summary of DG options in India [52]

DG options	Type	Technology status	Capacity factor
Diesel	NR	C,I	N
Gas engine	NR	C	N
Micro turbine fuelled by natural gas	NR	D	N
Fuel cell fuelled by natural gas	NR	D	N
Wind turbines	R	C,I	13% Avg Max 30-38%
PV	R	C,I	Max 25%
Biomass gasifier	R	C	N
Gas Engine	R	Gasifier-I	-
Biomass Cogen.	R	C,I	50 % Higher if aux. fuel used

NR-Non Renewable; I-Indigenous; R-Renewable; D-Demonstration; C-Commercially available technology; N- Not constrained by the supply.

3.1 Wind Energy

India ranks fifth amongst the wind-energy-producing countries of the world after Germany, Spain, USA and China. Estimated potential is around 45000 MW at 50 m above ground level. Wind farms have been installed in more than 9 States. More than 95% of installed capacity belongs to private sector in seven States. A good number of wind turbine manufacturers are active in India and producing Wind Electric Generators (WEGs) of rating 225 kW to 2100 kW. A large number of water pumping windmills and small aero-generators have been installed in the country. wind-solar and wind-diesel hybrid systems have also been installed at a few places. The Ministry of New & Renewable Energy (MNRE), Govt. of India has established a centre for wind energy technology at Chennai with field test station at Kayathar to act as technical focal point for wind power development in the country. Financial assistance for renewable source of energy is available through Indian Renewable Energy Development Agency (IREDA), a supporting arm of MNRE. **Table 4** shows the wind power potential and power generated till March 2008.

Table 4: Estimate wind power potential and actual generation in India

State of India	Gross Potential (MW)	Million Units
Andhra Pradesh	8275	1020
Gujarat	9675	2924
Karnataka	6620	5581
Kerala	875	n/a
Madhya Pradesh	5500	469
Maharashtra	3650	6958
Orissa	1700	2135
Rajasthan	5400	n/a
Tamil Nadu	3050	26748
West Bengal	450	n/a
Total	45195	45827

Note: Gross potential is based on assuming 1% of land availability for wind power generation in potential areas (source: MNRE (ErstwhileMNES)).

Table 5: Equivalent saving of coal & other pollutants by use of wind power generation (31.03.08)

Description	Total Saving in k'tons
Substitution of Coal	1,83,30,800
Sulphur di-Oxide[SO_2]	2,97,896
Nitrogen Oxides[NO_X]	2,06,222
Carbon di-Oxide[CO_2]	4,58,27,000
Particulates	24,632

Renewable energy is the ultimate answer to the climate change and global warming. This carbon free energy is seen as energy of the future whose development and deployment requires all possible encouragement. It has come into centre stage in all international deliberations on the future of the planet in the context of global warming. The year 2007's Nobel Peace Prize being conferred to the Inter-Governmental Panel on Climate Change (IPCC) is a testimony to the World-Wide realization that global warming and climate change are the stark and the biggest challenge the world has to grapple with. **Table 5** shows the saving in coal and reduction in pollutant due to wind power generation till March 2008 in India.

3.2 Solar Energy

India receives solar energy equivalent to over 5,000 trillion kWh per year. The daily average solar energy incident varies from 4 - 7 kWh per square meter of the receiving area depending upon the location. A target of 50 MW has been set for solar power generation during the eleventh five year plan, which is likely to be achieved.

A total of 33 grid interactive solar photovoltaic power plants have been installed in the country with financial support from the Government. These plants, with aggregate capacity of 2.12 MW, are estimated to generate about 2.55×10^6 kWh of electricity in a year. In addition, around 1.45×10^6 decentralized off-grid solar photovoltaic systems aggregating to about 125 MW capacities have been installed in the country, which is capable of generating about 150×10^6 kWh in a year. Further, a collector area of about 2.15×10^6 square meters has been installed for solar water heating applications. Typically, a solar water heating system with 2 square meters of collector area can generate energy equivalent to up to 1500 kWh of electricity when the system is used for about 300 days in a year.

3.3 Biomass

A target for addition of 1700 MW capacity, consisting of 500 MW of biomass power projects and 1200 MW of bagasse cogeneration projects has been proposed during XI plan period i.e. up to 2012. A cumulative biomass power potential of about 18,000 MWe from the surplus of agro residues have been estimated in the country. The States of Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal are having potential for setting up biomass based power projects of 100 MW or above. The biomass power potential in the identified districts of the above States ranges from 10 MW to 100 MW. Sugar mills having crushing capacity of 2500 tons of cane crushed per day in the States have an estimated potential of about 5000 MW surplus power generation through optimum bagasse based cogeneration.

3.4 Small Hydro Power

Six hundred eight small hydro power projects (up to 25 MW capacity) with an aggregate capacity of 2015 MW have been set up in the country. The annual estimated generation from these projects is 4028×10^6 kWh per year. A target of adding 1400 MW from small hydro power has been planned during the 11th Five Year Plan. **Table 6** shows the potential and installed capacity of renewable energy sources (RES) till March 2005 in India. It can be observed from Table 6 that India has tapped very small fraction of available renewable energy sources. However, Government is promoting RES with different policies.

Table 6: Renewable energy in India (on 31.03.05)

Source/System	**Estimated potential**	**Installed capacity/nos.**
Wind power	45 000 MW	3595 MW
Biomass power	16 000 MW	302.53 MW
Bagasse cogeneration	3500 MW	447.00 MW
Small hydro	15 000 MW	1705.63 MW
Waste to energy - Municipal solid waste Industrial waste	 1700 MW 1000 MW	 17 MW 29.50 MW
Family-size biogas plants	12 million	3.71 million
Solar street lighting systems	—	54 795
Home lighting systems	—	342 607
Solar lanterns	—	560 295
Solar photovoltaic power plants	—	1566 kWp
Solar water heating systems	140 M-m^2 of collector area	1 M- m^2 of collector area
Solar photovoltaic pumps	—	6818
Wind pumps	—	1087
Biomass gasifiers	—	66.35 MW

4. Key Issues in DGs Integration to Power Systems

DG offers several advantages such as (i) increased voltage support, reliability, price elasticity, efficiency and ancillary service provisions, and (ii) reduced emission, security risk, market power, cost of electricity, system energy loss, T&D requirements. However, there are several important and key issues, and challenges in the integration of DGs in the power systems.

4.1 Operation and Control

DG output is varied according to the local load variation. DG power output can also be controlled independently of the local loading of the area. This control mode is implemented if DG operation follows price signal, which might or might not correspond to the local load variations, or DG follows the availability of natural resources, like solar or wind power. In this case, DG might adversely affect the voltage control functionality of the network by increasing the variations between the maximum and minimum voltage level, compared to a situation when DG is not available. Since the minimum voltage level could remain (usually at a high load, no DG situation) but the maximum voltage level could increase, e.g. in low load situations with DG operating at maximum production and at a unity power factor. Generally speaking, DG can provide some challenges to the traditional voltage, frequency and power control [53].

Due to large penetration of DG, there is risk of control and stability issues. If a circuit breaker in a distribution system opens, it could results in an islanding of a DG unit. If the loss-of-mains is not detected by the DG unit, for example due to insufficient fault current, the DG unit will continue to operate. If the DG unit is able to match active and reactive power of the load in the islanded system precisely, then the islanded system could continue to operate without any problem. It is, however, very unrealistic that DG will exactly match the load in the system during the time the circuit breaker opens, hence large frequency or voltage variations will occur when the DG unit tries to supply load. Hence, most interconnection rules require a loss-of-main detection system which automatically disconnects the DG unit in case of a loss of main and the unit remains disconnect until the grid is restored [54-55].

4.2 Optimal Location

There are several methods available for suggesting the optimal location of DGs for various objectives. Based on the priorities of the objectives, analytical hierarchical process is used to suggest the best location of DGs. The suggested methods are good enough for the present condition of the power system which is keep on changing due to various reasons such as expansion of the network, load concentration, structural and regulatory changes, etc. The optimal location may not be optimal after years. Moreover, with growing penetration level of DGs, optimal locations keep on changing and a new coordinated planning study is required to find optimal location. Availability of fuel supply system in future will also affect the optimal location of DGs.

4.3 Modeling Issues

When the penetration level increases a certain threshold, it will no longer be appropriate to model static loads characterized by the amount of active and reactive power being consumed. The importance of the modeling of the new DG technologies has already been realized by the researchers and engineers and resulted in a number of scientific articles reporting the development of dynamic models of fuel cell systems, micro turbines, doubly fed induction machines, and generic loads [56-59]. Depending on the dynamical phenomena of interest, various models can be used in the analysis and simulations. For dynamic or transient stability study, it is extremely important to have models of the system reflecting the main dynamical features of the system with reasonable accuracy. This implies that the owners of DG should make all relevant technical characteristics of DG available. Here, not only the static characteristics of the DG units are important, but also the characteristics of the main controls such as the governor, voltage regulator, and excitation system of a synchronous generator, etc. should be available [60].

4.4 Protection System Requirements

Depending on the characteristics of DG (its rated power, technology used, mode of operation), the location of DG and network configuration, the impact of DG on the over current protection may vary. This clearly indicates that DG will certainly impact the protection scheme of the distribution grid. If the protection system of DG units is able to detect the fault and rapidly disconnect from the network, DG will not interfere with the normal operation of the protection system. Most interconnection standards, therefore, require disconnection of DG if a fault occurs. Nowadays, more and more distribution networks are automated and equipped with SCADA systems. The protection scheme must be properly coordinated and designed.

4.5 Change of Short Circuit Capacity

The installation of new distributed generators in the distribution networks potentially increases the level of short circuit capacity (SCC). Although sometimes, it is desirable to have a high SCC, e.g., at the point of connection of the inverter of a line commutated HVDC station or in the presence of large loads with rapidly varying demands, in general the increase of the SCC potentially indicates a problem [61].

4.6 Power Quality

Different DGs have different characteristics and thus create different power quality issue. The effect of increasing the network fault level by adding generation often leads to improved power quality. A notable exception is that a single large DG, e.g. a wind turbine, on a weak network may lead to power quality problems particularly during starting and stopping [62]. Excessive use of power electronics devices and modern controls introduces the power quality problems and moreover, these devices are very prone to power quality problems.

4.7 Stability

Traditionally, distribution network design did not need to consider issues of stability as the network was passive and radial, and remained stable under most circumstances provided the transmission network was itself stable. However, this is likely to change as the penetration of these schemes increases and their contribution to network security becomes greater. The areas that need to be considered include transient (first swing stability) as well as long-term dynamic stability and voltage collapse [27, 63-64].

4.8 Commercial Issues

In order to support the development of active distribution networks and extract corresponding benefits associated with connecting increased amount of DG, new commercial arrangements need to be developed. Generally, three approaches are possible: (i) to recover the cost of implementing active management directly through the price control mechanism (increasing the amount of recoverable capital and operating expenditure associated with active management); (ii) to establish an incentive scheme that would reward companies for connecting DG; (iii) to establish a market mechanism, outside of the regulatory framework, which would create a commercial environment for the development of active networks.

4.9 Regulatory Issues

In the absence of a clear policy and associated regulatory instruments on the treatment of DGs, it is very likely that this type of generation may to thrive. In order to foster the required changes, there is a clear need to develop and articulate appropriate policies that support the integration of DG into distribution networks. An appropriate regulatory policy of Government should be required for future growth of DGs.

4.10 Role in New Market Regime

DG does not only displace the energy produced by central generation but also the associated flexibility and capacity. DGs can play vital role in the electricity markets emerging all over the world. Depending on the market structure where these are install, DGs can participant in the energy markets (day-ahead, hour-ahead or real time, if exist) and can be used to provide ancillary services (AS) so as to improve the economic viability of some DG projects. Several technical and regulatory/policy constraints may be faced by the DGs.

4.11 Economic Factors

Due to developing technologies of distributed generators, the major risk to the existing and the upcoming DGs is to economically sustain in the future. The agreement for supply future load and government commitment for their survival are their concerns. It is expected that DGs should get reasonable return from the market so that more expansion can be sought.

4.12 Unbalancing

Various DGs, which supply to the network in single-phase, are available. If it exists, the unbalancing of the system will occur and it should not increase beyond the permissible limit. Moreover, operation of DGs suffers with the unbalancing of loads in the phases. Their performance deteriorates due to unbalancing.

4.13 Demand Response Effect

Electricity market exists in several countries and demand response is encouraged for better economics of the electricity market and customers. These demand responses may not be very beneficial to the DGs as they may lose revenue due to demand response.

Conclusions

This paper addresses the distributed power generation technologies and their impacts on the future power system. The various DGs options incorporated in Indian power system are described along with future potential and options. Due to rising fossil fuels and environmental concerns, the penetration of distributed generation coming from the renewable energy sources is increasing and expected to grow further in the future. This increasing penetration brings various technical and economical challenges in integrating the distributed generations in to existing power systems, which are critically examined.

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